X-662-74-236

PREPRINT

NASA TM X- 70734

GAMMA RADIATION FROM THE CRAB NEBULA ABOVE 35 MeV

D. A. KNIFFEN

R. C. HARTMAN

D. J. THOMPSON

G. F. BIGNAMI

C. E. FICHTEL

H. ÖGELMAN

T. TÜMER

(NASA-TM-X-70734) GAMMA RADIATION FROM THE CRAB NEBULA ABOVE 35 MeV (NASA) 11 p HC $4.00 CSCL 03B

N74-32241

Unclas

G3/29 46673

GSFC

GODDARD SPACE FLIGHT CENTER

GREENBELT, MARYLAND

Gamma Radiation From the

Crab Nebula above 35 MeV

D. A. Kniffen, R. C. Hartman, D. J. Thompson,

G. F. Bignami*, C. E. Fichtel

NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

H. Ögelman, T. Tümer

Middle East Technical University

Ankara, Turkey

*ESRO Postdoctoral Fellow on leave from LFCTR, Instituto di Fisca dell' Universita di Milano, Italy

Observations of electromagnetic radiation from the Crab have been made to at least a GeV[1] and possibly as high as 10^{12} eV[2,3]. The Crab is unique among strong X-ray sources in that the major component in the low energy range (1 to 10 KeV) shows little or no temporal variation. A small ($\leq$ 10% at 10 KeV) pulsed component from NP0532 is observed in the X-ray region; but its strength relative to the constant component increases with increasing X-ray energy. Gamma ray observations of the Crab in the 15 to 100 MeV range have yielded rather uncertain results with reported upper limits [4,5] and fluxes [6 to 10] in apparent or near conflict. Since the reported intensities were just marginally detectable above atmospheric background with the balloon experiments which produced the observations reported thus far, this seems understandable.

Here we report observations of the Crab above 35 MeV made with the high energy gamma ray telescope flown on SAS-2. The detector and technique are described in detail by Derdeyn et al. [11], and in summary by Fichtel et al. [12].

The data were obtained during the week of December 14-21, 1972. The Crab direction remained about 5° from the experiment axis for the entire exposure. The absolute timing accuracy of the SAS-2 satellite and the ground station was sufficient to allow separation of the pulsed component. Because of the finite angular resolution of the SAS-2 detector, an angular cone of acceptance for gamma rays must be included in the final analysis. We used a 6° cone for gamma rays with measured energies from 35 to 100 MeV and 4° for energies above 100 MeV. Appropriate account was taken of the portion of the flux which is calculated on the basis of the known detector angular resolution to fall outside these circles.

The arrival time of each gamma ray was compared to the radio pulse time using predicted pulse arrival times provided by J. M. Rankin, Arecibo Radio Observatory, and derived as described in ref. 13, (Fig. 1). An independent timing analysis was made using a program developed at GSFC based on a pulse prediction program provided by D. C. Backer.

Notice that peaks do occur at both the positions of the main and secondary radio pulses, and that there is a constant component above the general background from the Crab region. Although the statistics are limited, the probability of finding by chance sixteen gamma rays in a bin where a peak was predicted, when the average based on the eight bins where no peak was expected is five, is less than 10^{-4}. The probability of finding peaks of the observed size in both bins is then extraordinarily small. Since the absolute timing uncertainty for SAS-2 was about 1 millisecond, selecting markedly smaller intervals of time than those shown in Fig. 1 does not produce peaks of increased significance.

The total flux of gamma rays above 35 MeV is estimated to be $(15.8 \pm 4.2) \cdot 10^{-6}$ photons cm^{-2} sec^{-1} and that of the pulsed component, using bins 1 and 5 only in Fig. 1, to be $(6.2 \pm 2.8) \cdot 10^{-6}$ photons cm^{-2} sec^{-1}. The total flux above 100 MeV is $(3.2 \pm 0.9) \cdot 10^{-6}$ photons cm^{-2} sec^{-1}, and the pulsed component above 100 MeV is (2.2 ± 0.7) 10^{-6} cm^{-2} sec^{-1}. These results are shown in Fig. 2, along with data from other experiments. The unpulsed component appears to become a progressively smaller fraction of the total flux as the energy increases. Above

140 MeV, only a 95% confidence upper limit of $0.7 \cdot 10^{-6}$ photons cm^{-2} sec^{-1} can be set for unpulsed component whereas a finite flux of $(1.30 \pm 0.46) \cdot 10^{-6}$ photons cm^{-2} sec^{-1} was seen for the pulsed component. The situation contrasts markedly with the low energy X-ray region, where only 10% of the radiation is pulsed (ref. 14).

The most striking feature of the spectral distribution of the electromagnetic radiation from the Crab between 10^4 and 10^9 eV is the shift from a predominantly unpulsed total flux at the lower energy, to one which is predominantly pulsed. The spectral shape of the pulsed emission, although only poorly known, can be approximated by a power law with energy spectral index of $\alpha \sim 1$ to about a GeV. Qualitatively, this picture is consistent with the Shklovsky (15) model of synchrotron emission from the speed of light cylinder with a steady flux of much lower energy photons from the region of smaller field. With a magnetic field in the Nebula between 10^{-4} and 10^{-3} G one needs electrons accelerated up to 10^{12} - 10^{13} eV to produce gammas in the 100 MeV energy region. Such electron energies have indeed been predicted in models of particle acceleration for the Crab pulsar.

It is interesting to compare the gamma ray results discussed here with those for the Vela region reported by Thompson et al. (16). The gamma ray fluxes from the two regions above 100 MeV are nearly equal, the Vela flux being $(5.0 \pm 1.2) \cdot 10^{-6}$ photons cm^{-2} sec^{-1}. But the Crab spectrum in the gamma ray region seems to be a simple extension of the X-ray spectrum, whereas in the case of the Vela source the gamma radiation is quite hard and substantially larger than an extension of the X-ray spectrum to that energy region. The Vela intensity and spectra are consistent with the gamma radiation being the result of about $3 \cdot 10^{50}$ ergs of cosmic ray nuclei from the Vela supernova interacting with the local matter.

It is not inconsistent with the data from the Crab supernova also to have released a few times 10^{50} ergs of cosmic rays, because being about four times further away, the gamma radiation from cosmic ray interactions would be approximately 16 times less intense, assuming the local matter density is not grossly different from 1 to 2 nuclei cm^{-3}. The gamma ray intensity near 100 MeV from supernova nucleonic cosmic rays, then, would be more than an order of magnitude less than the pulsed radiation at the present time.

So, a consistent picture of the present data ascribes a very different origin to the gamma ray intensity from the Crab to that from Vela, with the Crab gamma radiation being due to the same mechanism responsible for the X-ray emission and the Vela gamma radiation being due to the nucleonic component of the cosmic rays interacting with the local matter.

The authors would like to express their appreciation to J. M. Rankin of the University of Iowa and Robert Payne of the Arecibo National Astronomy and Ionosphere Center for providing NP0532 predicted pulse arrival times. We also thank D. C. Backer of GSFC for assistance in the development of timing programs.

RFEFERENCES

1. McBreen, B., Ball, S. E., Jr., Campbell, M., Greisen, K., and Koch, D., Astrophys. J. 184, 571-580 (1973).

2. Grindlay, J. E., Astrophys. J. Lett. 174, L9-L17 (1972).

3. Fazio, G. G., Hemken, H. F., O'Mongain, E., and Weekes, T. E., Astrophys. J. Lett. 175, L117-L122 (1972).

4. Frye, G. M., Jr., and Wang, C. P., Astrophys. J. 158, 925-937 (1969).

5. Kettenring, G., Mayer-Hasselwander, H. A., Pfeffermann, E., Pinkau, K., Rothermel, H., and Sommer, M., Proc. 12th Internat. Cosmic Ray Conf. 1, 57-62 (Hobart, 1971).

6. Browning, R., Ramsden, D., and Wright, P. J., Nature 232, 99-101 (1971).

7. Albats, P., Frye, G. M., Jr., Zych, A. D., Mace, O. B., Hopper, V. D., and Thomas, J. A., Nature 240, 221-224 (1972).

8. Kinzer, R. L., Share, G. H., and Seeman, N., Astrophys. J. 180, 547-549 (1973).

9. Parlier, B., Agrinier, B., Forichon, M., Leray, J. P., Boella, G., Marschi, L., Bucheri, R., Robba, N. R., and Scarsi, L., Nature Phys. Sci., 242, 117-120 (1973).

10. Helmken, H., and Hoffman, J., Proc. 13th Internat. Cosmic Ray Conf. 1, 31-35 (Denver 1973).

11. Derdeyn, S. M., Erhmann, C. H., Fichtel, C. E., Kniffen, D. A., and Ross, R. W., Nucl. Instr. Meth. 98, 557-566 (1972).

12 Fichtel, C. E., Hartman, R. C., and Kniffen, D. A., Astrophys. J. Lett. 186, L99-L103 (1973).

13. Rankin, J. M., Counselmann, C. C., III, and Richards, D. W., Astron. J. 76, 686-690 (1971).

14. Fishman, G. J., Harnden, R. F., Jr., and Haymes, R. C., Astrophys. J. Lett. 156, L17-L110 (1969).

15. Shklovsky, I. S., Astrophys. J. 159, (1970).

16. Thompson, D. J., Bignami, G. F., Fichtel, C. E., and Kniffen, D. A., Astrophys. J. Lett. 190, L51-L53 (1974).

17. Kurfess, J. D., Astrophys. J. Lett. 168, L39-L42 (1971).

18. Orwig, L. E., Chupp, E. L., and Forrest, D. J., Nature Sci. 231, 171-172 (1971).

19. Laros, J. G., Matteson, J. L., and Pelling, R. M., Nature Sci. 246, 109-111 (1973).

Fig. 1. Distribution of gamma ray arrival time in fractions of a pulse period for gamma rays above 35 MeV from the direction of NP0532. M and S refer to the predicted main and secondary pulse times as determined from radio observations (Rankin, private communication).

Fig. 2. Spectrum distribution of fluxes observed from the region of the Crab nebula.

— — —	= $0.7E^{-0.9}$ pulsed flux, ref. 19
━ ━ ━	= $21.8E^{-1.29}$ total X-ray flux, ref. 19
▧	= SAS-2 total flux
●	= SAS-2 pulsed flux
▽	= ref. 17
□	= ref. 1
○	= ref. 10
▲	= ref. 7
■	= ref. 6
◇	= ref. 8
△	= ref. 9
◆	= ref. 18
✱	= ref. 14
⊤↓	= ref. 5

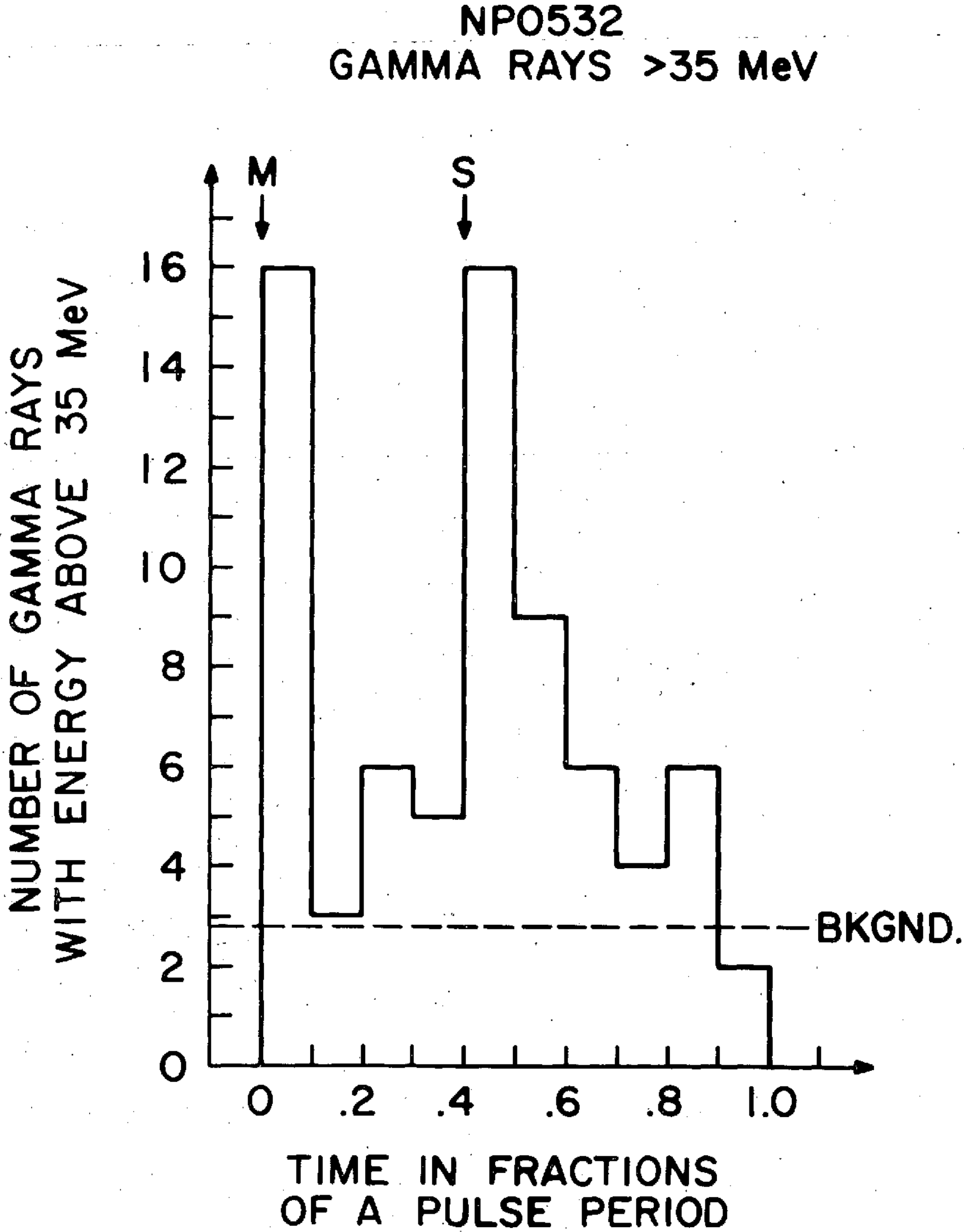
NP0532
GAMMA RAYS >35 MeV
M
S
NUMBER OF GAMMA RAYS
WITH ENERGY ABOVE 35 MeV
0
2
4
6
8
10
12
14
16
BKGND.
0
.2
.4
.6
.8
1.0
TIME IN FRACTIONS
OF A PULSE PERIOD

Fig. 1

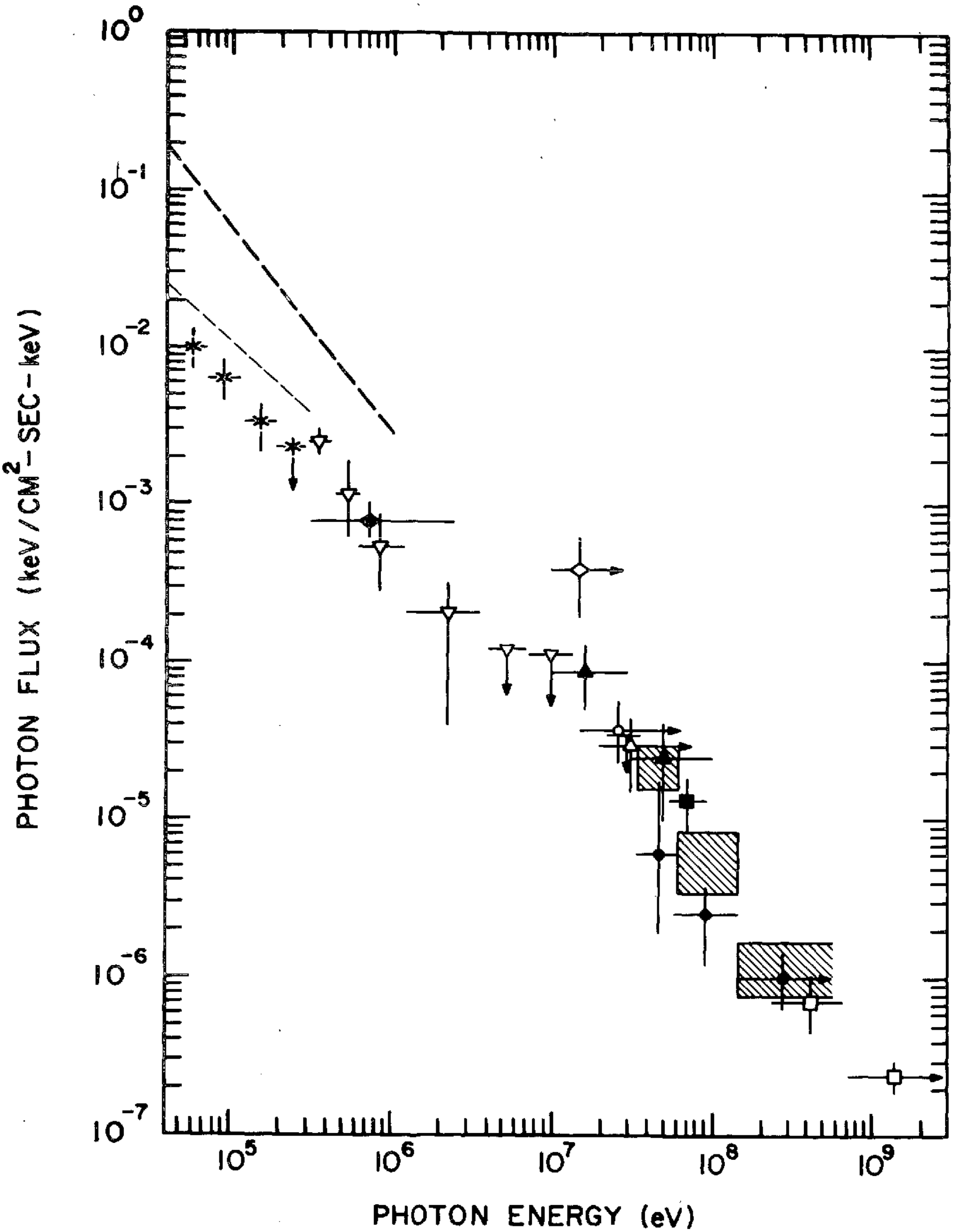

Fig. 2

NASA–GSFC